A 3D Uranium Casting Simulation from Preheat to Cooldown

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The Telluride project is developing a highly parallel, coupled-continuum scale, multi-physics simulation tool (*Truchas*). Key applications include metal-alloy casting processes of interest to the LANL foundries and development of a metal fuel-casting process for the Global Nuclear Energy Partnership (GNEP). The metal-alloy casting typically involves preheating the mold assembly by induction coils, melting the metal in the crucible, delivering the molten metal via gravity pour, and cooling to room temperature via conduction and radiation. Recently, the Telluride project has attained the capability to model this entire casting process, from initial preheat to final cooldown [1].

The numerical simulation is completed in corresponding stages: heatup, fill, and cooldown. The simulation begins by preheating the assembly, shown in Fig. 1(a). The fill stage is modeled on a smaller mesh containing only the graphite molds and vacuum using the final enthalpies from the heatup stage as initial conditions. The uranium is introduced through an inlet velocity and temperature boundary condition maintaining the mass inflow rate from the casting [Fig. 1(b)]. Finally, the mold is allowed to cool via radiative and conductive exchange to the walls of the vacuum chamber. As the uranium cools down, it transforms from liquid to the solid Γ phase at temperature T=1406 K, Γ to β at T=1048 K, and β to α at T=941 K.

The cooldown stage is modeled without and with thermo-mechanical deformation of the mold and cast [Fig. 1(c)]. Enthalpies and volume fractions from the fill stage, along with the enthalpies from the heatup stage, are mapped to a full mesh. For both simulations, heat conduction, view-factor radiation, and isothermal phase change are calculated. The simulation with thermo-mechanical deformation is calculated on a smaller mesh similar to the fill stage mesh. This mesh contains gap elements to allow for gap formation and sliding between the uranium and the mold.

Simulation results were compared with thermocouples located inside and outside the mold for each stage of casting. Comparisons were used for validation of the simulation results, sensitivity studies of parameters such as conductivity and emissivity of the insulating felt (Fig. 2), and insight into including effects such as thermo-mechanical deformation during cooldown (Fig. 3).

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[1] S. Cummins and K. Lam, "An Overview of a 3D Plutonium Casting Simulation: From Mold Preheat to Cooldown," Los Alamos National Laboratory Report LA-UR-06-0751.

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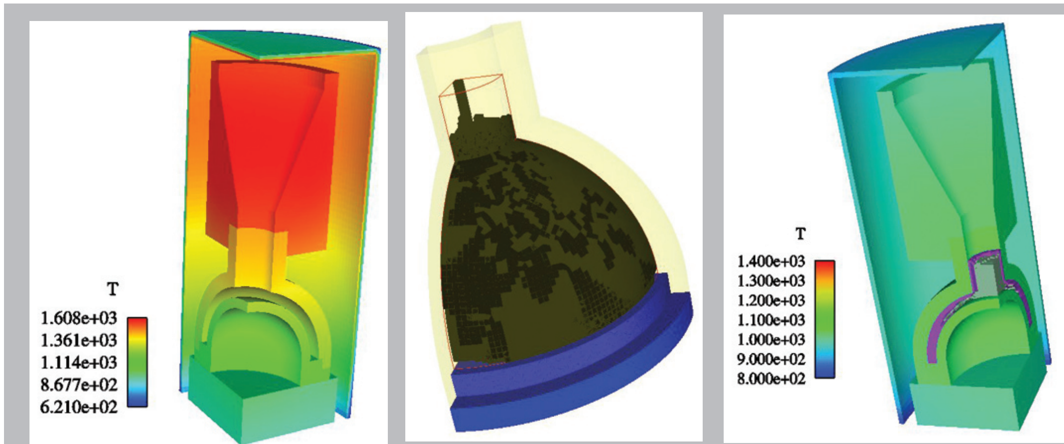

Fig. 1. (a) The heatup stage is simulated using the full mold assembly. The final temperature gradient at t=4550s is shown. (b) The fill stage, simulated on a smaller mesh, is shown after 15s (t=4565s). The entire fill takes approximately 16.3s (t=4550s to t=4566.3s). (c) The cooldown stage without thermo-mechanical deformation is again simulated using the full mold assembly. The temperature gradient shown is at t=6766s (after 2200s of cooling). The purple and grey inside the mold indicate the solid Γ and liquid phases of uranium present, respectively.

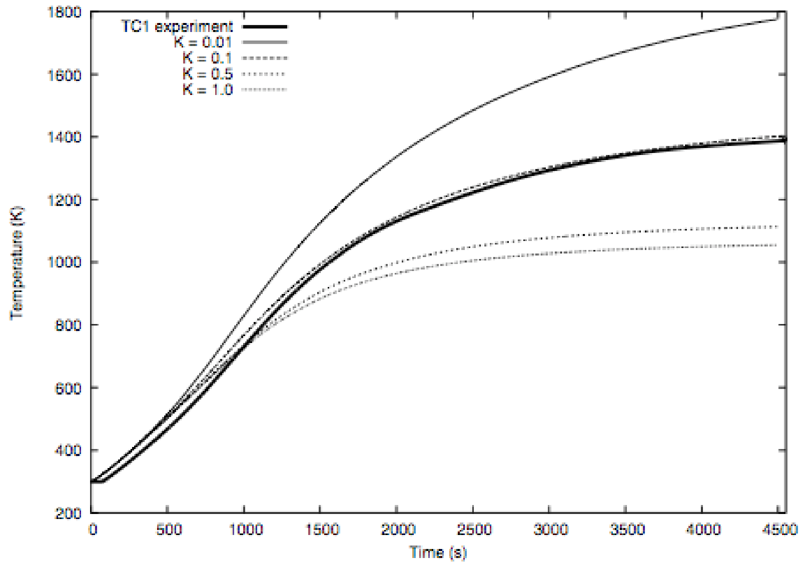

Fig. 2. Sensitivity of the temperature profiles to the conductivity of the insulating felt for the outer mold is shown. Conductivity values include K_{felt} = 0.01, 0.05, 0.1, 1.0. The solid line is the thermocouple data extracted from the casting. The range of results highlights the need to better understand such parameters.

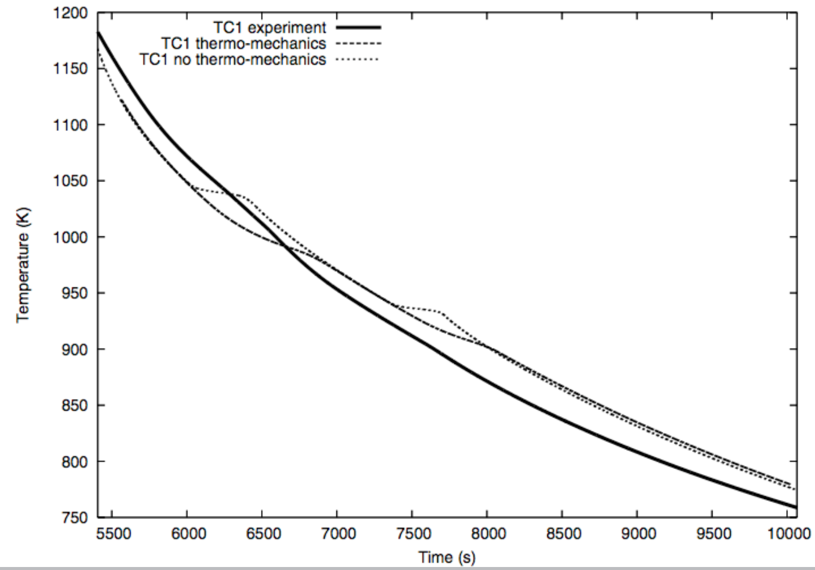

Fig. 3. Temperature profile for thermocouple located on the outer model compared with the simulation results with and without thermo-mechanical deformation. The results without thermo-mechanical deformation clearly show the iso-thermal phase transitions that are inconsistent with the thermocouple data. This discrepancy highlights the importance of including such effects.